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THE ORIGIN OF THE DÉBRIS-COVERED MESAS OF BOULDER, COLORADO

At the base of the mountains south of Boulder, Colorado, is found a series of table lands, or mesas, which rise 300 to 500 feet above the bed of Boulder Creek, and which slope away from the mountains at an angle of about 3½°. Mesas of a similar nature are found at numerous points along the mountain front, some of them much more extensive than the ones of which I write. This article is the result of a study of those included between Boulder Creek and South Boulder Creek. Their location is shown in Fig. 1. A photograph (Fig. 2) shows their general aspect and their relation to the foothills. Fig. 3 is an east-west section of the mesa shown in the photograph, giving its structure. A sheet of unconsolidated fragmental material, 25 to 50 feet in thickness, rests upon the eroded surface of the upturned Cretaceous formations, principally the Fort Pierre shale. The Benton, Niobrara, and Dakota are inconspicuous at this point, owing to the proximity of the Boulder arch described by Eldridge.[1] This covering of débris forms the protecting cap of the mesas. It is composed almost wholly of sandstone and conglomerate from the Red Beds of Permo-Trias age, which formerly covered the mountain front and which still rise about 2000 feet above the level of the plains. Their serrate peaks are shown along the lower mountain front in Fig. 2. At this point the Red Beds dip at an angle of 48°. The fragments of the detrital capping vary in size from grains of sand to bowlders twenty feet in diameter. They are notably angular, bearing little evidence of long continued water action, and are very imperfectly sorted. Coarse and fine materials are bedded together in the most intimate relations. Originally they formed a continuous sheet of débris, the greater part of which has been destroyed by subsequent erosion.

[1] U. S. Geol. Surv., Mon. 27, p. 105.

The mesas are bordered by rather sharp declivities. Between the foot of these declivities and the flood plains of the creeks is an inclined surface which may be called the mesa-terrace. It is a wide shelf-like surface extending from the base of the mesas proper to the border of the present flood plains, where in some cases it is terminated by a bluff, while in others it descends in a gentle transition slope not always separable from the mesa-terrace, making one continuous incline from the base of the mesas to the border of the flood plain, into which it passes by imperceptible gradations. Where this transition slope has been

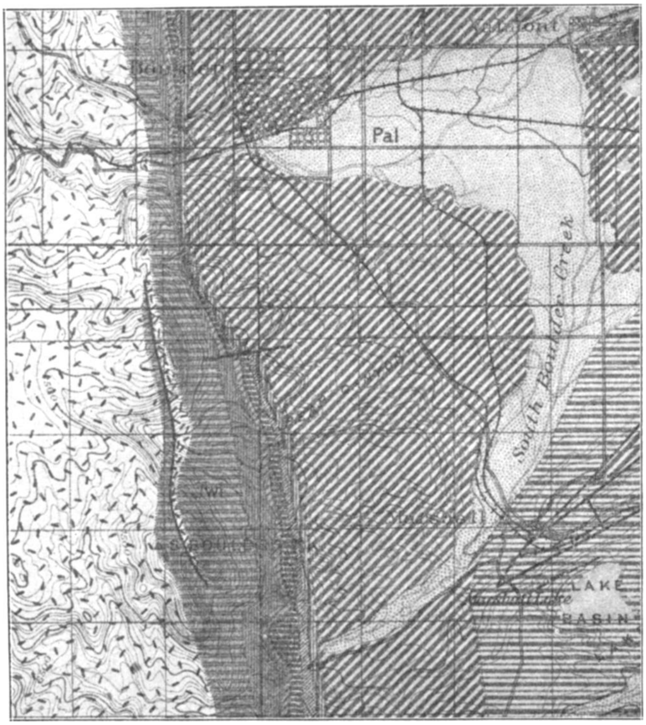

FIG. 1.—The geological formations in order from the left (west) are: (1) Crystallines of the Mountains; (2) Lower Red Beds; (3) Upper Red Beds; (4) Como (Atlantosaurus Beds); (5) Dakota; (6) Benton; (7) Niobrara; (8) Ft. Pierre and Fox Hills; (9) Laramie.

destroyed by the existing streams, and a bluff or steep slope formed, the mesa-terrace impresses one as being possibly due to a former cycle of erosion. But where the transition slope is intact and the surface of the mesa-terrace passes gently into that of the flood plain the two are seen to be obviously due to a continuous process of erosion uninterrupted by any notable change in the attitude of the land.

The substructure of the mesa-terrace is similar to that of the mesas proper, but its surface is more irregular and the covering of fragmental material is not uniform in thickness or in distribution. The mesa-terrace is shown, in part, in the middle foreground of Fig. 2 with the buildings resting upon its surface. The covering of the mesa-terrace differs from that of the mesas, first, in the thinner and more irregular nature of the sheet of débris; second, in the more rounded character of the fragments; and third, in the greater content of crystalline material. The débris on the tops of the mesas contains about 1 per cent. of crystalline material, while the débris on the mesa-terrace is made up of sandstone and crystalline material in varying proportions. The crystalline material of the mesas is chiefly quartz and metamorphic sandstone, such as is contained in the conglomerate of the Red Beds, from which it very probably came, in the main. The crystalline material on the mesa-terrace is largely granitic, and is usually much water-worn and in an advanced stage of decomposition.

At still lower levels is found the sheet of débris which is now gathering over the valley bottoms of the existing streams. These streams are forming wide bottom lands[1] which have a gradient at Boulder of about fifty feet to the mile. In this recent débris the material is imperfectly sorted and is composed largely of crystalline rock from the mountains. The fragments are well rounded and the granitic constituents are not usually decomposed.

In these three stages we find an instructive series; first, the mesa tops, composed mainly of sandstone débris of an angular, slightly worn character; second, on the mesa-terrace the mantle

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[1] See Pocket Map, Mon. 27, U. S. Geol. Surv.

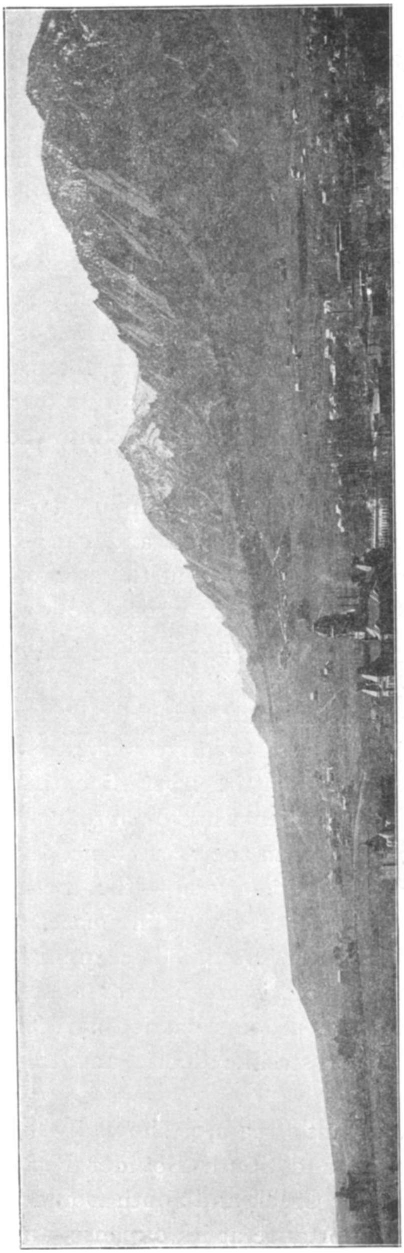


FIG. 2.—Photograph of the region south of Boulder, from a point north of the city. The surface of one of the mesas and the mesa-terrace appears in the horizon at the left. The point at the extreme right is the peak of Green Mountain, and that in the background is South Boulder Peak.

has proportionately less sandstone, more metamorphic, and more granitic material, the latter in a much decomposed state; and third, the recent valley drift, composed mainly of well rounded crystalline material of which undecomposed granitic rock forms a large part.

There is one other group of phenomena which must be considered before attempting an interpretation. There is a large mesa near the mouth of Bear Canyon (see map, Fig. 1) on which the largest bowlders are found in great numbers. This mesa is also the highest in the region under discussion. A line drawn from its top, parallel to the foothills and touching the tops of the mesas to the north, would have a gentle slope in that direction, *i. e.*, toward Boulder Creek. A similar though indistinct slope toward South Boulder Creek is indicated by some remnants south of this mesa. The mesa-terrace has a corresponding inclination.

From the foregoing facts the conditions of formation may be inferred :

1. At the time the mountains began to assume their present elevation they were faced, if not covered, with the sedimentary formations whose truncated edges are now exposed along the foothills. At an early stage of erosion the young streams carried away the shales, since they lay uppermost, and formed the grade upon which the sandstone débris was deposited. The streams found little of a coarse or enduring nature with which to form a deposit and thus prevent the cutting down of the shales to a low gradient until they had cut back into the Red Beds.

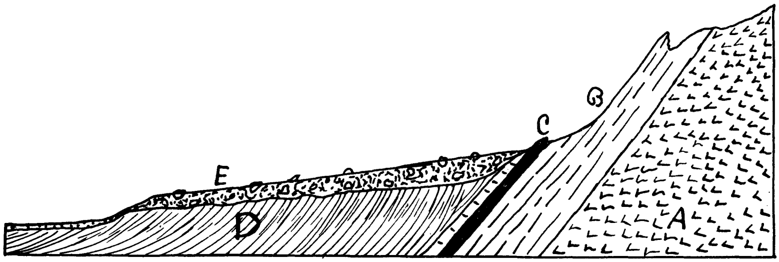
2. When the erosion began to work effectively upon these, much coarse and enduring material was loosened and carried down the high gradient of the mountain flank, but the streams were unable to carry all of the coarse parts of it across the lowered gradient of the shale tract, and hence deposited it as the mantle of the present mesa tops.

3. As the streams by headward extension reached back into the crystalline area, they derived a less relative amount of material from the Red Beds and more from the crystalline area. Besides, by reaching backward, their gradients had been reduced and they reacquired some eroding power in the mesa zone, and hence cut into it and formed the lower surface — the mesa-terrace — on which is found relatively more crystalline material and relatively less of that from the Red Beds. The granitic material of this mantle being relatively old is much decomposed.

4. The later deposits represent the process carried farther, giving a still larger proportion of crystalline débris, and this, being young, is undecomposed.

At first Bear Creek was an important stream, as shown by the wide gap between Green Mountain and South Boulder Peak. But, for reasons unexplained, Boulder Creek and South Boulder Creek, on either hand, gained in importance at its expense, and as they more effectually lowered their channels a new grade was produced in the mesa zone, represented now by the mesa-terrace. At the same time this new grade was covered with material formed by a mingling of the old mesa-tops débris with the fresher material from the mountains.

The process of forming the grade and covering it with débris in this manner may be studied in minutest detail at the present day in Boulder Creek Valley. As the present streams are cutting away the mesa-terrace and mingling its fragmental material with the fresh material from the mountains, so the more ancient streams undermined the sheet of débris on the mesa-tops and mingled it with that of the then flood plains.



Section of formations shown in FIG. 2.

FIG. 3.

E—Fragmental débris.
D—Fort Pierre Shale.
C—Dakota.
B—Red Beds.
A—Crystallines.

The production of the abrupt slopes forming the sides of the mesas, and to a less extent bounding the mesa-terrace on the one hand, and on the other hand the lateral inclination of the surfaces of both, is well illustrated in Boulder Creek Valley. Before issuing from the crystalline area Boulder Creek has a high gradient and little of its energy is spent in cutting sidewise. Where it passes to the shale formations at Boulder, its gradient becomes lower and much of its energy is spent in cutting laterally. The result is a comparatively slow lowering of the bed of the stream and a comparatively swift migration laterally in the shale region. The migration is at present toward the south. The city of Boulder is built upon the ground recently abandoned by the stream. A north-south section through the city (see map, Fig. 1), cutting directly across this recently formed grade, shows a slope of the surface to the south of nearly fifty feet to the mile. The tops of the mesas and the surface of the mesa-terrace have an inclination somewhat greater than this but in the opposite direction.. It is near the city of Boulder that the most conspicuous slopes are found bordering the mesa-terrace. The transition slope has been cut away and bluffs formed fifty feet high in places. Should this process be continued to the extent of reducing the mesa-terrace to the lateral proportions of the mesas, the transition slopes would all disappear, and the bounding slopes of the mesa-terrace would present essentially the same aspect as those of the mesas. The probable action of the stream in producing the northern inclinations of the mesa-tops and the mesa-terrace together with their bounding slopes, and the southern inclination of the valley bottom by means of lateral migrations is illustrated in Fig. 4.

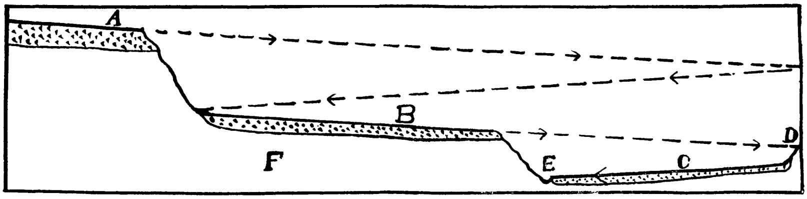


Fig. 4.—Diagrammatic section from the mesa (*A*) south of Boulder City, to the northern border of the present valley bottom, illustrating the assigned origin of the lateral inclinations of the mesa tops, mesa-terrace and valley bottom. *A*=mesa; *B*=mesa-terrace; *C*=valley bottom on which the city stands; *E*=Boulder Creek; *F*=Fort Pierre shale. The dotted lines represent the migrations of Boulder Creek together with the gradual lowering of its bed, the two processes combined producing the northward inclination of the mesa tops and the mesa-terrace, and the southward inclination of the valley bottom.

It is quite impossible to say what influence, if any, surface movement has had in changing the inclinations of the surfaces or determining special features. It seems, however, unnecessary to appeal to such movement, since the phenomena may be rationally explained by such processes of erosion and deposition as may be witnessed in the same region at the present time.

Conclusions.— From the phenomena observed in this region four conclusions may be drawn: (1) That the accumulations of débris forming the protecting surface of the mesas and the mesa-terrace are of fluviatile origin, and that in their mode of accumulation they differ in no essential respect from that in action over the valley bottoms in that vicinity at the present day. (2) That the mesa tops mark the level of a grade formed by the young streams soon after the adjacent mountains had assumed something like their present attitude. (3) That the three grades represented by (*a*) the mesa tops, (*b*) the mesa-terrace, and (*c*) the present valley bottoms do not seem necessarily to require the assumption of any change in the attitude of the land subsequent to the elevation of the mountains, but are the natural sequences of erosion as influenced by the local distribution and difference in hardness of the formations involved. (4) That the grades were formed and covered with débris by the streams at essentially the same time, and that it is contrary to the observed phenomena to assume that the grading was done at one period and the débris accumulated during some other period.

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